Femtosecond X-ray Source Instrumentation
Initial Concepts

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12/7/01

- **BPM's**

1) Single shot turn-by-turn capability, basic requirements:

   Dynamic Range = 0.01 nC – 5 nC

   <u>Resolution:</u>

   20 um @ 1 nC
   100 um @ 0.1 nC
   1000 um @ 0.01 nC

2) Electrostatic button pickups, 50 ohm, welded-in vacuum chamber for compactness.

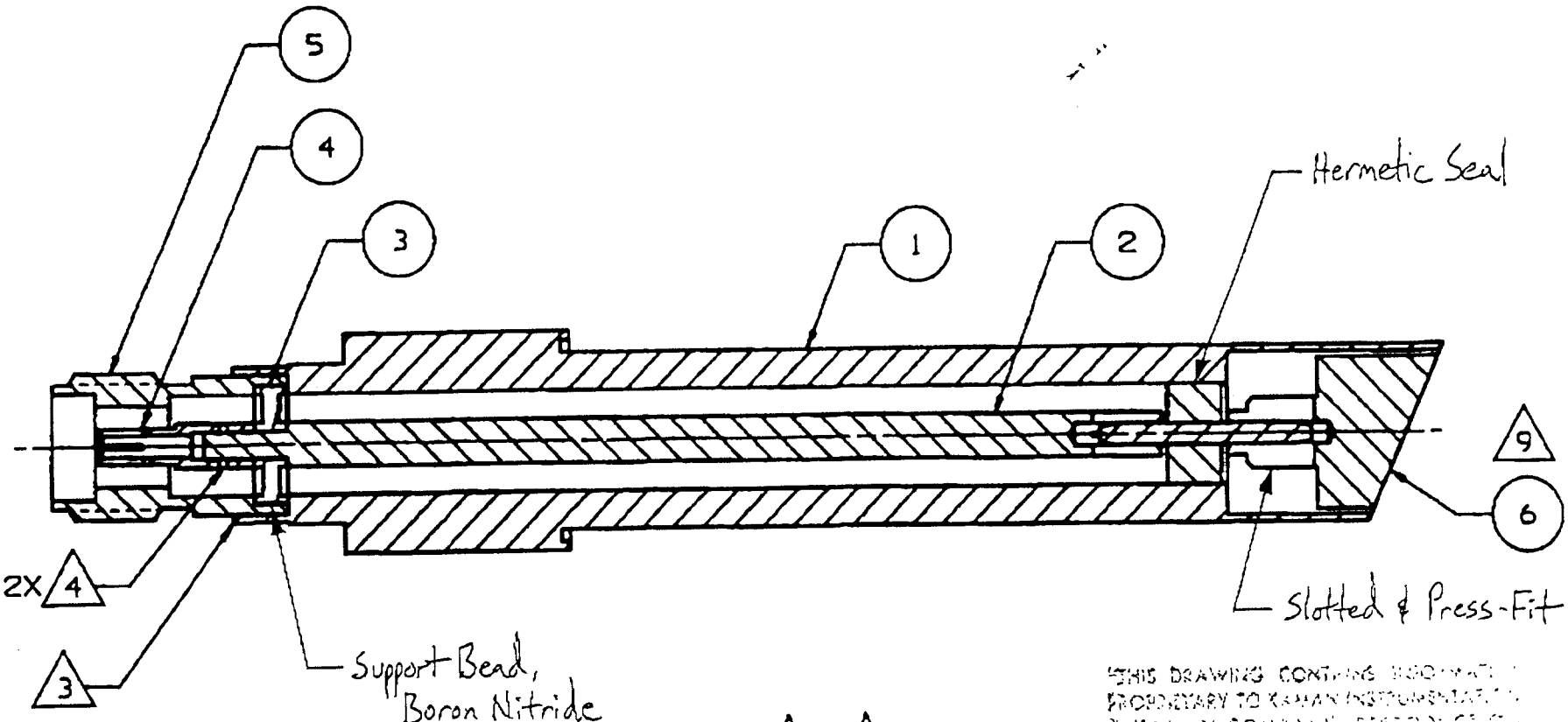
3) Detection at $3xf_{rf}$ = 3.9 GHz for maximum sensitivity, heterodyne down conversion of pulse to baseband.

4) Direct digitization of individual pickups with on a turn-by-turn basis (approximately 1MHz in linac) with a bunch rate of 10 kHz using multichannel A/D's. Allows bunch-by-bunch position determination.

5) Broad array of processing and calibration algorithms are possible at 10 kHz rate. Prototyping at ALS Linac possible.

6) Issue – ring turn time not equal (increasing pass lengths), special attention needs to be paid to clocking system.

7) Cost $4k per location?



SECTION A - A

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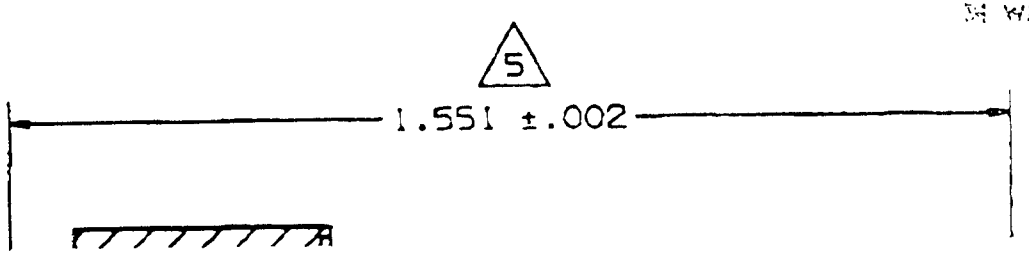

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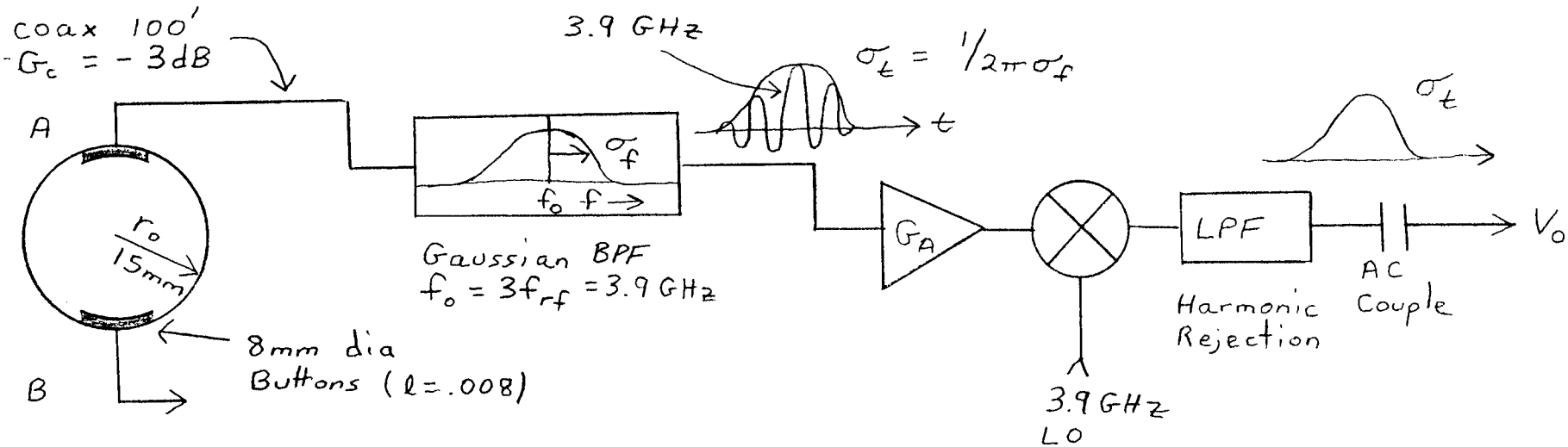
BPM Front-End Detection Model



For short bunches
BPF dominates

$$V_o(t) = \frac{G_c G_A g \ell q \, e^{-t^2/2\sigma_t^2}}{V_b C_b \sqrt{2\pi}\,\sigma_t}$$

$g = \ell / 8 r_o = .067$ $\quad V_b = 3\times10^8$ m/sec

$q = 0.01 - 5$ nC $\quad C_b = 4\times10^{-12}$ f (measured on similar existing buttons)

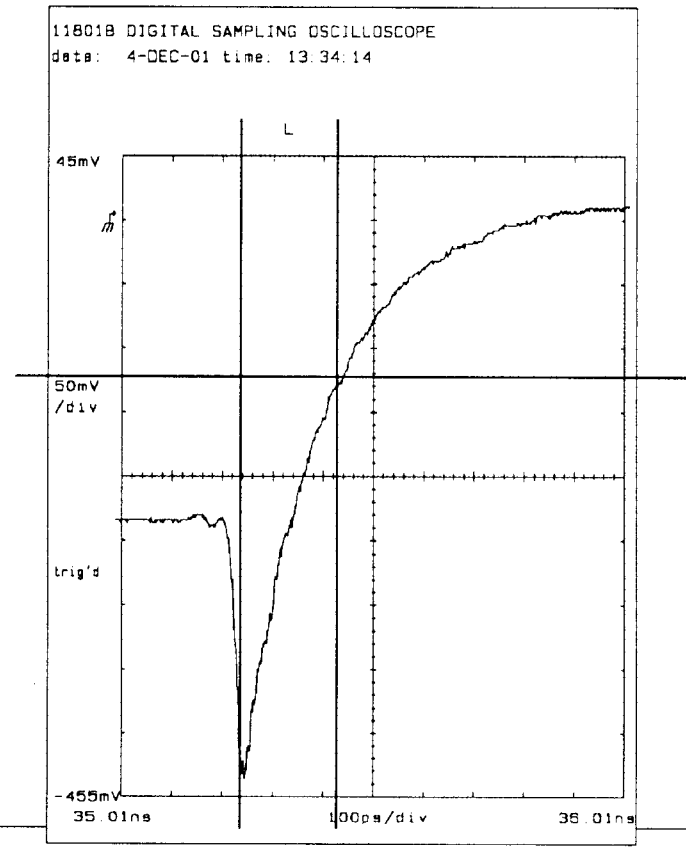
$\sigma_t = 6$ns for sampling accuracy, $\sigma_f \approx 27$ MHz

Example: $q = 1$nC, $G_c = .707$, $G_A = 1$ gives:

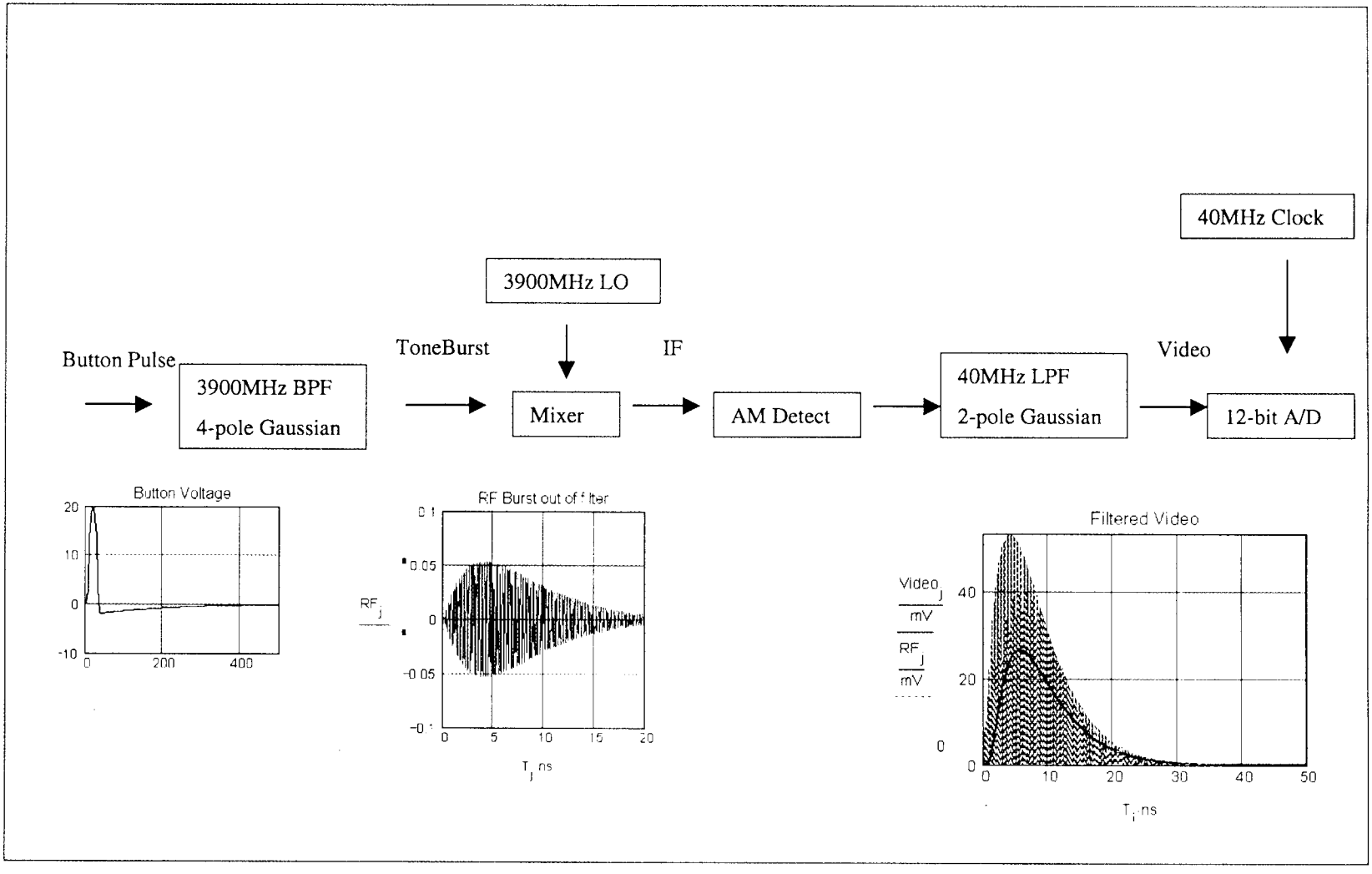
$$V_o(t) = .021\, e^{-t^2/2\sigma_t^2}$$ (21mV peak with no gain)

ALS Button TDR Measurement

- $C_b \approx 200ps / 50\Omega = 4pF$



Single Channel Block Diagram



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BPM Resolution

Specs:

$20\,\mu m \longrightarrow 1\,nC$
$100\,\mu m \longrightarrow 0.1\,nC$
$1000\,\mu m \longrightarrow 0.01\,nC$

Let: $V_\Delta = V_A - V_B$

$V_\Sigma = V_A + V_B = .042$ for $q = 1\,nC$

$$\frac{V_\Delta}{V_\Sigma} = \frac{2\Delta x}{r_0}$$

Assume: KT input noise + KT for amplifier, (KT = 3dB noise figure)

BW = 54 MHz

Equivalent "peak noise" $V_n = \sqrt{4KTRB}$ $R = 50\Omega$

Also, assume we want $V_\Delta \geq 3V_n = 2\times10^{-5}$ Volts

By looking at Δx required to acheive this voltage we get:

q	Δx_{min}
1.0 nC	3.6 μm
0.1 nC	36 μm
0.01 nC	360 μm

This is probably optimistic but it seems reasonable that specs can be met.

Also, probably need 6dB matching attenuators at buttons so multiply above by 2.

Electronics – A/Ds

- AD6644 Analog Devices ADC, 65 MHz, 14 bits
- AD9430 Analog Devices ADC, 210 MHz, 12 bits
- ADS852 Burr-Brown ADC, 65 MHz, 14 bits
- ADS808 Burr-Brown ADC, 80 MHz, 12 bits
- Many other options in 12-bit ≈ 100MHz
- Clock A/Ds at 40.6MHz (RF/32)

BPM Future Work

- More sophisticated front-end modelling.
- Down conversion techniques - heterodyne, IQ, intermediate (IF) frequency
- Digital electronics design
- Clocking system for increasing turn times.
- Literature search for existing systems
- Experimental work at ALS

- **BCM's (Bunch Charge Monitors)**

  1) "Off-the-shelf" from Bergoz, cost TBD.

- **BLM's (Beam Loss Monitors)**

  1) Most likely a combination of CLIC (coaxial linear ionization chamber), Cherenkov detectors and diode based detectors.

  2) CLIC used at SLAC is cheap and allows continuous pinpoint coverage. Sensitivity is approximately 3 mV/J to over 130mV/J depending on chamber gas mixture etc. May not meet 0.01nC loss spec. More information from SLAC required.

- **Bunch-by-Bunch/Turn-by-Turn Phase Monitor**

  1) Simple phase detection against MO at some harmonic of f_{rf}. Digitize result. Similar detection and clocking considerations as BPM

- **Photon-Based Diagnostics**

  1) Synchrotron light monitors for transverse profile. Frame grabbers. Pepper pot and imaging for emittance. Low- energy first turn needs study.

  2) Streak cameras for longitudinal measurements, $100 k per location.

- **Intercepting Diagnostics**

  1) Phospher screens (Alumina paddles doped with Chromox 6), "harps", etc. for steering, profile and emittance. *Significant Mechanical Engineering component.*

- **Laser-to-bunch timing –** See John Byrd talk

  1) Ultra stable RF phase-lock –loop techniques. Femtosecond measurement issues, AM-to-PM noise conversion. Prototype what has already been done in the field and take it from there.

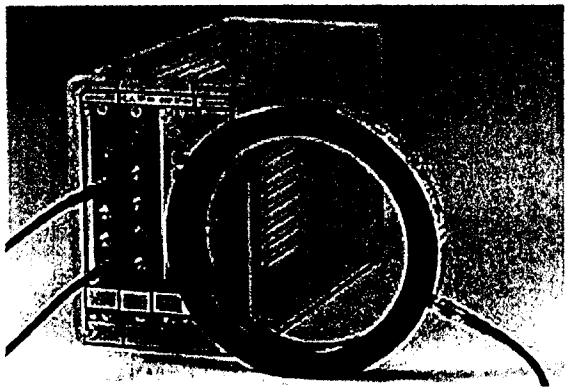
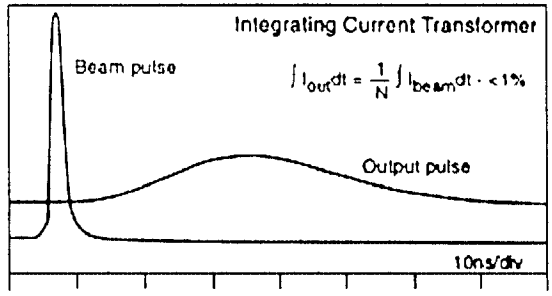
Beam Charge monitors

Off the shelf Beam Integrating Transformer (BIT) from Bergoz.

i) Very wide band

ii) Will measure .1 nC to 1 % accuracy

iii) Noise floor for 1nC ~ 8 pC

iv) Can operate at 10 Khz

v) Cost per unit approx: $20K